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Effects of Symbol Brightness Cueing on Attention During a Visual Search of a Cockpit Display of Traffic Information

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Introduction

With the likelihood of pilots acquiring more responsibility for real-time flight-path replanning, designers face new difficulties in creating advanced flight deck displays that provide the required situation awareness and decision support tools. In particular, a Cockpit Display of Traffic Information (CDTI) must depict sufficient information to provide situation awareness, while keeping attentional demands and time-to-search at a minimum. There are several possible approaches to this problem. One is to use visual features to segregate information on a display into more and less important items, and using these features to direct attention. Such features may vary in terms of inherent salience (involuntarily attracting attention), or simply in terms of a visual coding that is cognitively mapped to differing levels of importance. Therefore, display element features and knowledge about target attributes can both play important roles in enhancing visual search performance within an informationally-dense display such as a CDTI.

These concepts have previously been examined in theoretical and applied settings, and are commonly referred to as differences between top-down and bottom-up attentional control in visual search tasks. At the theoretical level, research has shown that salient items may be involuntarily processed first in visual search tasks, indicating that bottom-up processing is important in the deployment of attention (e.g., Joseph & Optican, 1996; Kawahara & Toshima, 1997). By way of example, Pashler (1988) showed that when color was irrelevant in a visual search task, participants still took longer to locate a target when distractor color singletons appeared. Similarly, Theeuwes (1991a, 1992) found that irrelevant singletons could attract participants' attention while performing visual tasks.

On the other hand, research has shown that what appears to be an involuntary, or automatic, capture of attention is often the result of top-down processing, where a prior mental set tunes the attentional system to respond automatically to specific features (e.g., Folk & Remington, 1998; Jonides & Yantis, 1998; Gibson & Jiang, 1998). For instance, Folk and Remington (1998), in a modified spatial cueing paradigm, demonstrated that top-down "control settings," such as the defining feature of a target, could direct participants' attention within a display.

At a more applied level, how highlighting can direct a user's initial attention to targets, in turn reducing search time, has also been studied (e.g., Morse, 1979; Smith & Goodwin, 1971, 1972; Stewart, 1976). However, the benefits of such highlighting appeared to be contingent on either bottom-up factors, such as the type of highlighting (e.g., color, brightness, blinking), or top-down factors, such as the level of highlighting validity, and the probability that operators attend first to the highlighted options (Fisher & Tan, 1989). Therefore, while top-down and bottom-up processes have both shown their individual impact on control of attention, their interactive effects on attention control and visual search performance may be equally important to assess. Accordingly, the present study investigated the simultaneous impact of both top-down and bottom-up control of attention during visual search within a CDTI. A CDTI depicts the location of aircraft proximal to one's own aircraft (Ownship). An efficient CDTI ensures the pilot pays greater attention to aircraft that are likely to contain important information, and one method to accomplish this is to use a discriminative feature to distinguish which set of aircraft are potentially important, and which are less likely to be important.

The present study used relative intensity, or brightness, as the discriminative, or highlighting feature, and examined whether brightness, per se, would influence attention in the absence of any information about the relation between the brightness of a stimulus and whether that stimulus was the target (zero validity). This is an examination of a pure bottom-up effect. In addition, the effect of brightness was examined when participants were given information about this relation between the brightness of a stimulus and whether that stimulus was the target (full validity). This is an examination of a top-down effect, but one that may be influenced by bottom-up effects (i.e., search may be faster when directed to bright targets than when directed to dim targets).

For the current investigation, aircraft proximal to Ownship were presented on a CDTI. Participants were instructed to detect a single target aircraft on a collision course with Ownship. Depending on experimental conditions, all of the aircraft could be dim, all could be bright, or half could be dim and half bright (Mixed condition). Highlighting validity was tested in 2 experiments, one where the participant was informed in the Mixed condition if the target aircraft would be bright or dim (full validity), and a second experiment where the participant was *not* informed of target intensity in the Mixed condition (zero validity). The primary dependent measure was response time for the detection of the target aircraft.

Method

Stimuli and Design

The experiment utilized a CDTI with one Ownship symbol depicted by a white filled triangle (chevron) located at the bottom of the display, and 8 other aircraft symbols (unfilled chevrons) pseudo-randomly placed throughout the rest of the display (Figure 1). Chevron orientation corresponded to the direction the aircraft were traveling.

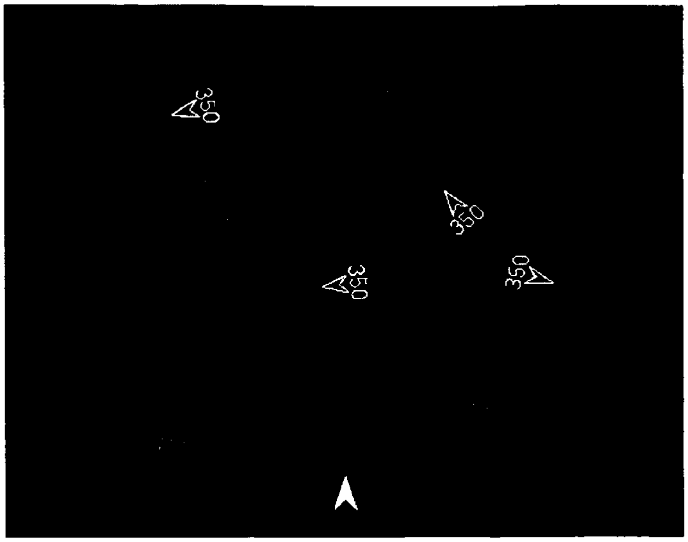

Figure 1. A CDTI showing Ownship and 8 aircraft.

The CDTI was partitioned into four equally sized x-y regions with either one or two aircraft randomly located in each region, generating a total of four or eight aircraft on the display (depending on experimental condition, discussed later). The target appeared equally often in each region in order to minimize possible location effects. When the target aircraft appeared in a particular region, it replaced a non-target aircraft; thus, there were always three or seven non-target aircraft paired with one target aircraft on the display. The placement and heading of each non-target aircraft was designed to miss Ownship by a visually wide margin. The altitude and speed of all aircraft were the same. Thus, it was obvious when an aircraft was a target.

Two within-participants variables were manipulated, *Mixture* and *Target Intensity*. Mixture display conditions included: the *Homogenous-8* condition (where all eight aircraft had the same intensity, either bright or dim), the *Mixed* condition (where four aircraft were bright and four were dim), and the *Homogenous-4* condition (where only four aircraft were depicted on the display, and all had the same intensity, bright or dim). The luminosity (intensity) levels for bright and dim aircraft were 1.81 cd/m^2 and 0.28 cd/m^2, respectively, against a black background of 0.0014 cd/m^2. Table 1 shows a matrix of the conditions.

Table 1. A matrix of the conditions.

Target Intensity	Condition Type: Mixed	Homogenous-8	Homogenous-4
Bright	3 Bright Aircraft 4 Dim Aircraft 1 Bright Target	7 Bright Aircraft 0 Dim Aircraft 1 Bright Target	3 Bright Aircraft 0 Dim Aircraft 1 Bright Target
Dim	4 Bright Aircraft 3 Dim Aircraft 1 Dim Target	0 Bright Aircraft 7 Dim Aircraft 1 Dim Target	0 Bright Aircraft 3 Dim Aircraft 1 Dim Target

The *"Directions"* manipulation distinguished the two experiments. In the *Undirected* experiment, participants were not told whether the target would be dim or bright prior to Mixed condition trials. In the *Directed* experiment, participants were told ahead of time whether the target would be dim or bright during Mixed condition trials.

The Undirected experiment consisted of six blocks of trials, one for each of the combinations shown in Table 1, with the exception that trials from Mixed conditions were intermixed to form two blocks with equal numbers of intermixed bright and dim target trials.

The Directed experiment consisted of six blocks, with one block of bright target trials and one block of dim target trials. Participants were informed about the target intensity at the beginning of each of the bright and dim Mixed blocks.

Participants

Forty-eight NASA-Ames employees (17 females, 31 males) volunteered their time to participate in the experiments. Each participant had normal or corrected-to-normal vision and was naïve as to the purpose of the study.

Apparatus

An Intergraph Pentium 200 system with a 20-inch (51 cm) diagonal SVGA (1024 x 1280) display was used. Viewing distance was approximately 48 cm, and the display updated at 60 Hz.

Procedure

The experimenter explained the main aspects of the task and procedures to each participant. Participants then read detailed instructions and began with 48 practice trials before proceeding to the experimental trials. For each trial, participants were asked to detect the one (target) aircraft on a collision course with Ownship. Once detected, participants pressed a button on a keypad indicating the target had been found. Detection times represented the time that elapsed between the onset of the aircraft in the display, to the time when the keypad was pressed. After the keypad was pressed, non-directional circles replaced the aircraft symbols, and the participants were instructed to use a mouse to select the circle where the target aircraft was previously located. This procedure assured that detection time was measured without contamination from the time needed to move the mouse to the target, and served to verify that participants had found the correct aircraft. Visual and auditory feedback was provided for incorrect target detections. For each trial, participants were asked to detect the conflicting aircraft as quickly as possible, without sacrificing accuracy. For each experimental condition participants responded to 48 trials, with optional self-paced breaks between each of the six blocks. Each participant completed a total of 288 trials. Participants were debriefed and thanked for their participation.

Results

The overall error rate for both the Undirected and Directed experiments was less than 1%. For each participant, detection times beyond three standard deviations from the mean were considered outliers and excluded from the analyses. Overall, 0.6% of trials were discarded.

Undirected Experiment

A repeated measures analysis of variance (ANOVA) was conducted for the Undirected experiment group. Mixture condition (Mixed, Homogenous-8, Homogenous-4) and Target Intensity (target being bright or dim) were the two within-participants factors (Figure 2). A significant main effect of Mixture ($F(2,46) = 29.917$, $p < .001$) was found. Follow-up analyses showed that the mean detection time of the Mixed condition was not significantly different from the Homogenous-8 condition, but was significantly slower than the Homogenous-4 condition ($F(1, 23) = 52.56$, $p < .01$). Mean detection times for the Mixed, Homogenous-8, and Homogenous-4 conditions were 1737, 1587, and 1145 ms, respectively.

In addition, a near-significant main effect of Target Intensity ($F(1,23) = 3.524$, $p = .073$) and a significant Mixture by Target Intensity interaction ($F(1, 23) = 6.719$, $p < .01$) were found. The main effect of Target Intensity showed that, on average, bright targets were responded to faster than dim targets (mean detection times for the bright targets and dim targets were: 1462 ms and 1517 ms). Follow-up analyses also showed that participants responded faster to the bright targets than to the dim targets in the Mixed condition ($F(1, 23) = 17.08$, $p < .01$). However, there was no significant difference between bright and dim conditions for the Homogenous-8 or Homogenous-4 conditions. In addition, there was no significant difference in the mean detection times for the bright targets in the Mixed condition, and either the bright or dim targets in the Homogenous-8 condition. This suggests that the mixed presentation hurt the detectability of dim targets, but left the detectability of bright targets unchanged, and equal to the Homogenous-8 targets.

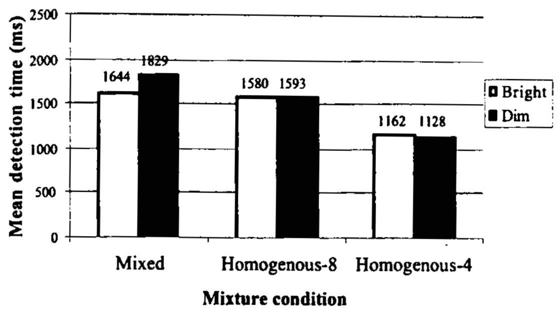

Figure 2. Mean detection times as a function of Mixture condition and Target Intensity in the Undirected experiment.

Directed Experiment

A repeated measures ANOVA was conducted for the Directed experiment, with Mixture and Target Intensity as the two within-participants factors (Figure 3). Main effects for Mixture ($F(2,46) = 41.741$, $p < .001$) and Target Intensity ($F(1,23) = 16.287$, $p < .001$) were found. Overall, the Mixed condition yielded a significantly lower mean detection time ($M = 1262$ ms) than the Homogenous-8 condition ($F(1, 23) = 14.32$, $p < .01$, $M = 1497$ ms), yet a significantly greater mean detection time than the Homogenous-4 condition ($F(1, 23) = 38.08$, $p < .01$, $M = 1001$ ms). The main effect of Target Intensity showed that bright targets were responded to faster than dim targets ($M=$ 1088 vs. 1175 ms). Furthermore, there was a significant Mixture by Target Intensity interaction ($F(1, 23) = 18.46$, $p < .01$). It was evident that bright targets were responded to faster than dim targets in the Mixed condition ($F(1, 23) = 13.88$, $p < .01$) and Homogenous-8 condition ($F(1, 23) = 12.08$, $p < .01$) but ***not*** in the Homogeneous-4 condition.

The Target Intensity effect in the Homogenous-8 condition was surprising since it did not occur in the Homogenous-4 condition, or in the two homogenous

Unfortunately there was no apparent interpretation for why this effect should occur for eight, but not four targets; or why it should be different between the two experiments.

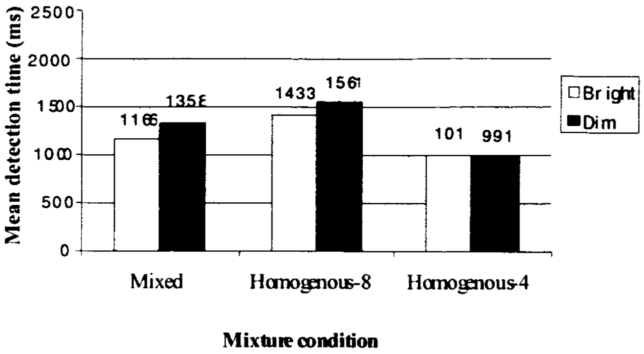

Figure 3. Mean detection times as a function of Mixture condition and Target Intensity for the Directed experiment.

Comparing across experiments

To examine the interactive effects of Target Intensity and Directions (directed vs. undirected), ANOVA's were conducted for each of the Mixture conditions – with Target Intensity as a within-participants variable, and Directions as a between-participants variable. For the Mixed condition, there was a significant main effect of Target Intensity ($F(1, 46) = 30.49$, $p < .01$), which showed that, on average, bright targets were responded to faster ($M = 1405$) than dim targets ($M = 1594$). There was also a significant main effect of Directions ($F(1, 46) = 7.36$, $p < .01$) with the directed group ($M = 1262$), on average, responding faster than the undirected group ($M = 1737$). There was no significant interaction. Similar analysis of the Homogenous-8 and Homogenous-4 conditions showed no significant effects.

Finally, we note that if participants were able to completely ignore aircraft with the irrelevant brightness level in the Mixed condition, then performance in the Mixed and Homogenous-4 conditions should have been approximately the same. However, this did not prove to be so. In the Directed experiment, where the aircraft with irrelevant brightness levels were removed (i.e. the Homogenous-4 conditions), there was an average of 496 ms improvement relative to the Homogenous-8 condition. However, when participants were given directions pertaining to the intensity set among which the target should reside, there was only an average 261ms improvement. That is, only 53% (261/496) of the potential improvement was realized.

Discussion

The present study investigated the effects of target intensity and highlighting validity, and their potential interaction on visual search performance with a CDTI. It was found that there was an improvement in target detection performance when participants were informed ahead of time which intensity level – bright or dim – to focus their attention on when searching for a target. This supports the idea that top-down processing aids search and detection performance.

However, this top-down effect was only about half what might have been expected if there was a substantial bottom-up, 'pop-out' effect. It is possible the difference in brightness was not great enough (though the bright targets were set at the maximum possible for our CRTs, brighter targets could be possible on other types of monitors). Furthermore, in preliminary evaluations it was determined that the dim targets could not be made dimmer without making them difficult to perceive. The applied relevance of this finding is that it may take a large brightness difference to generate additional savings in search time.

On the other hand, Figures 2 and 3 show that for both the directed and undirected experiments, target intensity in the Mixed condition seemed to independently influence search performance, causing the detection of dim targets to be slower than detection of bright ones. Thus, there was a bottom-up effect of intensity on performance.

One question to ask is whether this is a relative intensity effect, or if bright targets are simply easier to discriminate than dim targets. Three out of four of the homogenous conditions in the two experiments found no effect of brightness on detection time. In examining the numbers (three out of four), one could conclude that bright and dim are equally discriminable. Therefore, the effect seems to be one of relative intensity. This is what would be expected if attention were being preferentially deployed to bright targets before dim targets.

This simple explanation does not, however, account for all of the data. In the Undirected experiment, detection of the bright targets in the Mixed condition was no faster than the detection of dim or bright targets in the homogenous conditions. Instead, the effect of mixing the target intensities appears to slow down detection of the dim targets.

It should be pointed out that this could not be accounted for by simply proposing a masking effect of the bright targets on the dim targets. The reason for this is that approximately half of the targets (actually three out of seven) searched for prior to finding the bright target would have been dim. If detection of the dim targets was slowed due to bright target masking, then this would have slowed the overall detection of the bright targets too. This is not likely since the bright target Mixed condition in the Undirected experiment was responded to at a similar rate as the bright and dim Homogenous-8 conditions in the Undirected experiment.

On the other hand, if the dim targets are looked at but not recognized as targets, overall search times would be extended until the dim targets were re-sampled and perceived correctly. This would be a pure perceptual effect. An alternative to this explanation that focuses on decision processes would be that participants rejected distractors at the same rate for the bright or dim stimuli, but took longer to confirm a dim target. In either case, bright targets would be detected equally fast in the homogenous conditions, while detection of dim targets would be delayed.

Another explanation of this would be to assume two simultaneous effects in which the mixture condition simultaneously slowed down the overall search speed, while giving preferential attention to the bright stimuli.

Finally, the anomalous finding of a Target Intensity effect in the Homogenous-8 condition in the Directed experiment remains a puzzle. It may be due to some asymmetrical order effect, with the Mixed condition in the Directed experiment causing participants to change attentional control settings (see Folk and Remington, 1998). However, preliminary attempts by the present authors to find such an explanation have failed to reveal any convincing evidence for this hypothesis.

Other possibilities involve the relationship between the intensity level of the bright aircraft and Ownship. That is, the brightness of Ownship always matched the intensity level of the bright aircraft, thus a bias toward grouping the bright aircraft and Ownship together could have occurred. In future work, Ownship will be presented at an intensity level that represents mid luminosity between the bright and dim targets on the display.

Future work will focus on exploring the cause of the slower detection of dim targets when mixed with brighter distractors. The three hypotheses outlined above, missed dim-target detections, differential confirmation of dim and bright, and two simultaneous effects will be evaluated. Current efforts are focused on conducting an experiment using Signal Detection Theory methodologies to determine whether dim targets are responded to more slowly because of pure perceptual, or additional confirmation processes.

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13. ABSTRACT *(Maximum 200 words)*

This study investigated visual search performance for target aircraft symbols on a Cockpit Display of Traffic Information (CDTI). Of primary interest was the influence of target brightness (intensity) and highlighting validity (search directions) on the ability to detect a target aircraft among distractor aircraft. Target aircraft were distinguished by an airspace course that conflicted with Ownship (that is, the participant's aircraft). The display could present all (homogenous) bright aircraft, all (homogenous) dim aircraft, or mixed bright and dim aircraft, with the target aircraft being either bright or dim. In the mixed intensity condition, participants may or may not have been instructed whether the target aircraft was bright or dim. Results indicated that highlighting validity facilitated better detection times. However, instead of bright targets being detected faster, dim targets were found to be detected more slowly in the mixed intensity display than in the homogenous display. This relative slowness may be due to a delay in confirming the dim aircraft to be a target when it was among brighter distractor aircraft. This hypothesis will be tested in future research. Funding for this work was provided by the Advanced Air Transportation Technologies Project of NASA's Airspace Operation Systems Program.

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